

FLOATING SEMI-SUBMERSIBLE OIL PRODUCTION AND STORAGE ARRANGEMENT

The oil industry frequently makes use of floating production and storage systems for developing small remote oil fields. These generally use a converted crude oil tanker moored to a purpose built mooring buoy. To minimize the wave, current and wind forces on the tanker, the mooring is designed to allow the vessel to weathervane around the buoy under the influence of the resultant environmental force. Processing equipment is mounted on the deck of the vessel.

Oil production from the reservoir is via one or more sub sea wellheads, through a flexible flowline from each wellhead to the mooring buoy and from the buoy to the vessel. The system also incorporates lines to carry gas and/or water from the vessel to the wellheads. Also incorporated are hydraulic and electrical lines from the vessel to allow control of the sub sea wellheads. Since the vessel must be free to rotate around the buoy, the numerous fluid flow paths through the buoy result in the need for a complicated and expensive device known as a swivel. This is a precision-engineered piece of equipment subject to high pressure, high temperature corrosive fluids from the reservoir and hence must be manufactured faultlessly if high maintenance costs are to be avoided.

A further disadvantage of floating production systems that employ oil tankers is that they are highly susceptible to pitching, rolling and heaving. Since the separation of the oil, water and gas which comprise the fluid stream from the reservoir is effected by means of gravity separation in large pressure vessels, the sloshing of the liquids caused by the ship's motion can cause serious inefficiencies in the separation process.

An alternative type of floating production system which eliminates these problems is use of a semi-submersible vessel. Semi-submersible vessels have been used in the offshore industry for a number of years as mobile drilling vessels, crane barges, pipelaying vessels and dedicated floating production vessels. As shown in Figure 1, a semi-submersible vessel comprises a deck 1 supported above the water line

(OWL) on a number of columns 30. The columns extend from the deck to (typically) two flotation pontoons 31 located some distance below the water line. The advantages of a semi-submersible over a ship-shaped vessel are two-fold. Firstly, the area exposed to the waves at the water line is less for a semi-submersible than for a ship-shaped vessel and hence the horizontal wave forces are reduced. Secondly, because the pontoons which provide the buoyancy are much further below the water line than the underside of a ship, the vertical forces are much less. (This is because the effects of a wave rapidly decrease as one moves deeper into the water.)

The results of these advantages are that semi-submersible production vessels can be moored in the ocean without the need to provide weather vaning and that the sloshing of liquids in vessels on the deck is reduced.

Semi-submersible floating production systems (SSFP systems) however have two disadvantages. Firstly, there is no significant capability for storage of the produced oil. This means that they can only be utilized where a pipeline is provided to carry the produced oil to an onshore storage/processing facility or where a dedicated moored tanker ship is provided adjacent to the SSFP vessel.

The second disadvantage is that the amount of processing equipment which can be fitted on deck is limited because the centre of gravity of the SSFP vessel is raised as weight is added to the deck. This reduces the resistance to overturning of the vessel. This resistance to overturning is quantified in a property of the vessel known as the metacentric height (usually designated GM). A high GM means a high resistance to overturning.

A number of oil fields have been developed using a SSFP vessel which have used a converted second hand semi-submersible drilling vessel. Where the produced oil is viscous and needs large pressure vessels for separation or where gas injection or water injection equipment is required, new larger semi-submersibles are required to accommodate the equipment.

A number of attempts have been made to provide oil storage in a semi-submersible (British Patent Applications GB22116849, GB2207892, GB2188291 for

example). However, these allow storage of only a relatively small quantity of oil. These systems still require a dedicated moored tanker to store a marketable quantity of oil. The storage provided in the semi-submersible vessel only provides storage of a few days production to allow the storage tanker to travel to a nearby refinery for offloading.

According to one aspect of the present invention there is provided an oil storage assembly for a semi-submersible oil production vessel comprising a deck structure, at least two underwater pontoons for providing buoyancy to said deck structure, and a plurality of columns connecting said deck structure to said pontoons, characterised in that a concrete tank is attached below said pontoons, said concrete tank being subdivided into a plurality of chambers for storing fluid.

An arrangement for the storage of oil in accordance with the invention has the advantage that it provides a system for storing large quantities of oil which is not as susceptible to extreme environmental conditions, does not decrease, and in fact may be configured to increase the resistance to overturning of a rig with which it is used, and is easily maintained in situ.

More particularly, the present invention preferably provides a semi-submersible, floating production, storage and offloading system for the development of offshore oil and gas fields comprising a drilling vessel, an oil storage assembly according to the invention attached to the base of the drilling vessel, means for utilizing the drilling vessel's ballast pumps to add or remove water from the bottom of each chamber of the tank and means for directing produced oil into or out of the top of each chamber.

The present invention further provides a method of storing oil in an offshore floating oil production facility comprising the steps of attaching to the bottom of a pontoon structure a concrete tank, which is subdivided into a plurality of chambers, filling said chambers with at least one fluid to adjust the buoyancy of the production facility, and displacing said fluid from said chambers by pumping produced oil thereinto in a controlled fashion such that the mass of the tank and its contents is

maintained substantially constant.

Preferably, the concrete tank is divided into a number of chambers, in particular, by a plurality of fluid tight bulk heads, at least one of which chamber is located substantially centrally of the tank and is open at the top and bottom so as to provide a through opening in the tank. In this way, a rig can carry out drilling or workover operations with the tank attached.

Preferably, each chamber of the tank is maintained full of at least one fluid at all times so as to control the ballast of the arrangement. The fluids used in this way may, for example, be sea water, oil, natural gas or a mixture of two or more of these.

At least some of the chambers preferably include a first inlet/outlet pipe which terminated substantially at the bottom of the chamber and a second inlet/outlet pipe which terminated substantially at the top of the chamber. In particular, at least some of the chambers preferably include a water inlet/outlet pipe and an oil inlet/outlet pipe. Each such chamber is then at least partially filled with water prior to commencement of oil production, that water being displaced from the chamber through the water pipe as oil is added to the chamber by means of the oil pipe. In the same way, oil may be evacuated from the tank, for example to a tank for transport to shore, by displacement using water injected through the water pipe. The water pipe advantageously terminates close to the bottom of the chamber, since sea water is normally denser than oil, and preferably has a diffuser pipe on the end thereof so as to minimize the mixing of oil and water as water is pumped into the chamber. The oil pipe then preferably terminates at the inner face of the upper surface of the chamber, which arrangement has the advantage that it avoids the possibility of a gas pocket building up in the tank.

It has been found to be particularly advantageous for maintaining the mass of the tank and contents substantially constant as oil is produced or offloaded if a first plurality of chambers operate this oil over water storage arrangement, and a second plurality of the chambers operate with either oil, natural gas or a mixture thereof stored therein. In particular, each of the second plurality of chambers is preferably

provided with a first pipe which terminates proximate to the bottom of the chamber and a second pipe which terminates proximate to the top of the chamber, wherein as oil is produced it is pumped into the chamber through said first pipe, displacing gas already in the chamber out through the second pipe. Preferably, then, said second plurality of chambers are arranged in a cascade arrangement with each second pipe extending from proximate to the top of one chamber to the bottom of the next chamber in the cascade so as to form the first pipe for said next chamber. This arrangement has the advantage that the chambers of the cascade are filled or emptied in sequence rather than simultaneously, i.e. once the first chamber in the cascade is filled, it then overflows into the second. As a result, at any time only one of said second plurality of chamber contains a mixture of oil and gas - the rest being either filled with gas or with oil, thereby reducing the free liquid surfaces within the arrangement.

Preferably, the first plurality of chamber constitute substantially 80% of the chambers and the second plurality substantially 20% oil being fed or extracted from said first and second chambers simultaneously, preferably with substantially 80% of the flow being directed to said first plurality of chambers and substantially 20% to said second plurality. This has the advantage that, because the density of crude oil is substantially 80% that of sea water, a constant mass is maintained in the tank as oil is loaded or unloaded from the arrangement whilst at the same time the free surfaces of the fluids within the chambers is minimized, which is beneficial to the stability of the arrangement.

In an alternative embodiment, each chamber includes, in addition to said first and second inlet/outlet pipes, a third inlet/outlet pipe which terminates part way down the chamber, at a distance from the top of the chamber of substantially 20% of the height of the chamber. In this embodiment, the first pipe provides an inlet/outlet for sea water, the second an inlet/outlet for gas and the third an inlet/outlet for oil, all chambers of the arrangement being equipped with an identical piping arrangement and being fed simultaneously. A mixture of water and gas is then used to ballast each

chamber, each chamber being 80% filled with water with gas thereabove when no oil is present, the volume of gas within each chamber being varied as oil is added/removed therefrom so as to ensure that the volume of water displaced by the oil as it is pumped in is only 80% of the volume of oil. In this way, the overall mass of the arrangement is kept constant.

Some embodiments of the invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 shows a typical semi-submersible floating production system;

Figure 2 shows in perspective a semi-submersible drilling rig with a concrete tank attached in accordance with the present invention;

Figure 3 shows a sectional elevation of the drilling rig of Figure 2;

Figure 4 is a schematic diagram of the layout of the connection between the chambers of the concrete tank of Figures 2 and 3;

Figures 5 and 6 are further schematic diagrams showing how the chambers are connected;

Figure 7 shows additional detail of the drilling rig of Figures 2 and 3; and

Figure 8 shows an alternative gas/oil/water loading/offloading arrangement.

Referring first to Figure 2, the drilling rig 1 has a concrete tank 2 attached below columns 30 and the pontoons 31.

As shown in Figure 3, the concrete tank is segmented by fluid tight bulk heads in the form of internal concrete walls 3. At least one cell in the centre of the tank is constructed to be open at top and bottom to create a hole through the centre of the tank whereby the rig can carry out drilling or workover operations with the tank attached.

Also shown in Figures 3 and 5 for one chamber are the water inlet/outlet pipe 4 and the oil inlet/outlet pipe 5. The water pipe terminates in a diffuser pipe 6 close to the bottom of the chamber which minimizes mixing of the oil and water as water is pumped in. The oil pipe terminates at the inner face of the upper surface to avoid the possibility of build-up of a gas pocket. To maintain the mass of the tank and contents

constant as oil is produced or offloaded only 4/5 of the chambers operate on the oil over water principle shown in Figure 3.

Figure 5 shows a piping arrangement which ensures longitudinal stability of the tank by ensuring the centre of mass remains suitably stationary during the loading/unloading process of the oil over water chambers. The remaining 1/5 of the chambers utilize a gas over oil scheme employing piping as shown in Figure 6. Oil enters the first chamber A through oil pipe 9. As chamber A fills with oil, natural gas is vented via pipe 10 to chamber B. When chamber A is full, oil will then travel through pipe 10 to chamber B, displacing, in turn, the gas, via the link line into chamber C, and so on until all the chambers are full of oil and the gas has been vented from the final gas vent pipe 11. This process proceeds at the same time that 4/5 of the oil is being directed to the oil over water chambers. Because the density of crude oil is approximately 4/5 that of sea water this arrangement maintains a constant mass in the tank as oil is loaded or offloaded. These arrangements minimize the free surfaces of liquids inside the chambers which is beneficial to the stability of the vessel. Figure 4 shows an example layout for the chambers with those operating a gas over oil scheme arranged in a line along the centre of the tank and those operating a water over oil scheme being arranged symmetrically on either side so as to ensure lateral stability during the loading/unloading process.

An alternative arrangement to achieve this mass balance is shown in Figure 8. In this arrangement the loading system is identical for all chambers. Sea water inlet/outlet pipes are provided at the bottom of the chambers, oil inlet/outlet pipes are provided at 4/5 of the height of the chamber and natural gas inlet pipes are provided in the upper surface of the chambers. When no oil is on board, every chamber is filled 4/5 with sea water with natural gas above. As oil is produced it enters via oil pipe 26 and sea water is displaced via water pipe 25. At the same time, natural gas is released via the gas inlet/outlet pipe 27 to ensure that the volume of water displaced by the oil is only 4/5 of the volume of oil entering.

The invention is further characterised by the fact that the mass of tank and

contents is slightly greater than the buoyancy of the tank. This means that to bring the combined semi-submersible/tank structure to the same draft that the semi-submersible normally operates uncombined, some ballast water must be removed from the semi-submersible causing a further improvement in the metacentric height of the combined vessel. This arrangement creates a tensile force between the tank and rig.

A further characterization of the invention is that this tensile force can be changed to a compressive force which is beneficial to the fatigue life of the vessel by eliminating any gap between the underside of the semi-submersible pontoons and the upper surface of the tank.

By constructing the base of the tank of a material of greater density than the roof, the centre of gravity of the tank and contents is slightly below the centre of buoyancy of the tank. This increases the metacentric height of the vessel allowing an increased payload to be added to the deck of the semi-submersible.

The volume of the tank is sufficiently large such that when the tank is empty, with the drilling rig attached above it, the upper surface of the tank is a considerable distance above the water line. Accordingly, each chamber may be filled at least partially with gas, for example air, so as to reduce the total mass of the tank including its contents and hence reduce its draught so as to facilitate maintenance. This allows access to the piping above the upper tank surface, to the manholes in the tank for internal inspections, to the tank-to-semi-submersible connections and to all external parts of the semi-submersible. This allows the inspections required by classification societies to be carried out without the vessel needing to go to dry dock. The only parts of the vessel not inspectable in the dry are the underside and lower walls of the tank. Since the tank is constructed of concrete, periodic visual inspection by divers or remote underwater vehicle is considered sufficient.

Concrete as a structural material behaves best when loaded in compression. Tensile forces must be resisted by reinforcing steel embedded in the concrete. The required quantity of reinforcing steel can be minimized by maintaining the external pressure on the tank greater than the internal pressure. To achieve this the water

outlet line from each oil-over-water chamber is connected to a breaktank 12 located inside a column of the semi-submersible as shown in Figure 7. This breaktank is located below the elevation of the operating water level (OWL). The breaktank is vented to atmosphere 13 and the water level in the breaktank is maintained by level switches 14 and 15 acting on the semi-submersible's seawater ballast pump 16 and control valve 17 to add or remove water as necessary. To ensure that the oil system cannot overpressure the tank, the oil inlet/outlet is vented to atmosphere at a safe location 18.

Large centrifugal pumps 19 are required to offload the stored oil into shuttle tankers. Such pumps require a net positive suction head (NPSH) on their suction side in order to function effectively. Normally this is achieved by locating the pumps at a lower elevation than the bottom of the storage tank. The arrangement of the present invention allows the pumps to be located above the top of the tanks in a caisson attached to one of the semi-submersible columns where they can easily be removed by one of the rig cranes for maintenance but still be provided with a net positive suction head.

Also shown in Figure 7 are an oil export meter 20, a ballast water cleanup device 21, an oil in water alarm 22 and a gas/oil/water separator 23.

The invention is also characterised by the fact that all necessary valving, pumps and instrumentation for the seawater system can be located inside the columns of the semi-submersible where they are in a dry, benign environment and can be easily accessed for maintenance.

The invention requires no pipes or fittings protruding from the bottom of the tank. This allows easy construction onshore, skidding of the tank into the ocean, setting the tank on a suitable seabed for fitting to the semi-submersible.

The invention is also characterised by the ability to construct the connection between the tank and the semi-submersible rig in the dry even though this connection is underwater during normal operation. Once constructed the tank will be set on the seabed with a few metres of water above it. The semi-submersible at its minimum

draft will be floated over the tank and deballasted down on to the top of the tank. The tank is then deballasted sufficient to lift the semi-submersible clear of the water allowing the permanent connection to be constructed in the dry.

It will, of course, be understood that the proportion of 80% used above is connected to the relative density of sea water to crude oil and is therefore only an approximate value. Furthermore, in the event that the arrangement is utilized with liquids other than oil and/or water, the relative displacement quantities and/or the relative numbers of the first and second pluralities of chambers will then be in accordance with the relative densities of the actual liquids used.